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Scheduling irrigation to meet crop demands

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Scheduling irrigation to meet crop demands

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SUMMARY

In any climate in which precipitation is less than adequate for optimum crop growth, irrigation to relieve the moisture deficiency is potentially desirable. The actual water requirements of crops are fundamental to the determination of specific irrigation needs. This bulletin presents the water requirements for most field crops commonly grown in or proposed for southern Alberta. It also introduces procedures for translating these requirements to practical recommendations for efficient farm irrigation.

RÉSUMÉ

Dan toutes les regions où les précipitations sont insuffisantes à la croissance optimale des cultures, il peut être souhaitable de compenser le manque d'eau par l'irrigation. Il est fondamental de connaître les exigences en eau des différentes cultures pour déterminer leurs besoins d'irrigation dans une situation particulière. Ce bulletin donne les besoins en eau de la plupart des grandes cultures actuellement exploitées ou projetées dans le sud de l'Alberta. Il présente également des techniques de transformation de ces données en recommendations pratiques pour une irrigation efficace des cultures.

FOREWORD

In 1976, the Canada Department of Agriculture released Publication no. 1590, Scheduling Irrigation to Meet Crop Demands. This proved to be a useful bulletin primarily because of the specific crop evapotranspiration information which it contained.

Since 1976, water requirements have been determined for several additional crops. New procedures involving the use of computers promise to make application of the information even more effective. The revision of Publication no. 1590 to incorporate the new data and concepts has resulted in this Technical Bulletin. A separate publication provides a detailed description of the scheduling model and procedures referred to in the bulletin.

WHY PLANTS USE WATER

Plants require amazingly large amounts of water. Every day a leafy, actively growing plant uses five to ten times as much water as it can hold at one time. A good crop of wheat extracts enough water during the growing season to cover the field to a depth of 45 cm. In other words, about 1000 kg of water is needed to produce 1 kg of wheat, but only a fraction of this water is retained by the plants.

Why do plants remove so much water from the soil and expel nearly all of it into the air? Water is used to transport nutrients from the soil to green plant tissue where they are used in photosynthesis. Carbohydrates, the products of photosynthesis, are conveyed in water solution to storage organs such as seeds, roots, or tubers. Having transported the various materials to their destinations in the plant, the water simply evaporates through the stomata, tiny pores in the leaves. Besides transporting nutrients, this evaporation process, called transpiration, absorbs heat, cools the plant, and prevents the buildup of injuriously high temperatures.

Plant cells are like little water bags. Without internal pressure, called turgor, they lose their shape. Turgor pressure results because the concentration of salts and sugars in solution within the plant cells is higher than that outside the cells. When plants are amply supplied with water, the solution outside the cells is less concentrated than the solution within. Water tends to move through the cell membranes into the cells to equalize the concentration of both solutions. Thus, turgor pressure is high, and the plants maintain their shape. When plants have insufficient water, the solution outside the cells becomes more concentrated than the solution inside the cells, water moves out of the cells to equalize the concentration, turgor pressure drops, and the plants wilt. Consequently, herbaceous plants require ample water to maintain their rigidity and shape.

Plants automatically reduce the rate of transpiration when their water intake cannot equal the rate of water loss. They simply close their stomata when the water content of the leaf tissue declines. But this closure also prevents carbon dioxide from entering the leaf tissue and restricts photosynthesis and plant growth. When soil moisture is restricted or chemicals that close stomata artificially are applied, the rate of transpiration is reduced and crop yields are usually lowered.

During hot weather, low-volume sprinkling to cool the crop reduces transpiration. But the water saved by reducing transpiration is offset by increased evaporation losses. No overall saving of water is realized. When this procedure was tested under the climatic conditions of southern Alberta, neither yield nor quality of beans or potatoes was notably increased, provided that an adequate level of soil moisture was maintained.

The apparently extravagant use of water by plants can be reduced, but not eliminated. For example, the soil need not be wetted deeply when the crop is young and rooting is shallow. Nor is full soil moisture required when seeds have nearly ripened. But these water-saving measures only prevent loss of soil moisture through drainage or direct evaporation from the soil surface. Transpiration continues at a natural rate.

Water is used most efficiently when high-yielding crops and varieties are grown with optimum soil fertility, good cultural practices, and correct amount and timing of irrigation. These procedures ensure the greatest crop yield for each unit of water used. The method of irrigating does not significantly influence crop response.

THE SOIL-PLANT SYSTEM

The soil occupied by plant roots is the primary storage reservoir of water for the crop. But part of this water is held too tightly in the soil to be removed by plants. When soil moisture is reduced to this level, plants wilt; hence, the soil moisture is said to be at the wilting point.

Soils cannot always hold all the water that comes as precipitation or irrigation, and the excess drains away. Field capacity is the upper limit of water that the soil can hold after most of the excess water has drained away. The available water in the soil represents the field capacity minus the unavailable water, held by the soil at the wilting point.

As the available water is used by the crop, increasing suction is required to extract it. At field capacity, the suction required to extract the soil moisture is about 0.3×10^5 Pa, which is equivalent to the force required to lift the water about 3.4 m. At the wilting point, the suction required to extract the soil moisture is about 15×10^5 Pa, equivalent to the force required to lift water about 155 m. This figure represents the practical limit

at which plants can extract moisture. In fact, only about half the water held between field capacity and wilting point is said to be readily available. The remaining half becomes increasingly difficult for the plants to remove as extraction proceeds.

Plants function somewhat like water pumps, using differences in suction between the soil, plant, and air to take water from the soil and deliver it to the atmosphere. Heat from the sun warming the air, directly or by radiation from the soil surface, creates a difference in vapor pressure between the air and the leaves. When the suction exerted by the warm air exceeds that holding the water in the plant, water is transpired. Suction forces of adhesion, cohesion, and osmosis in the soil in contact with the roots tend to prevent the flow of water and plant nutrients into the plant. Within the plant, there are suction forces similar to those in the soil plus the additional effect of elevation. If the soil moisture suction is less than the suction that tends to move water into the roots, through the plant, and into the atmosphere, the crop can remove moisture from the soil. When soil moisture suction is greater than the moisture suction in the plant, the plant stops removing water from the soil and growth ceases.

EVAPOTRANSPIRATION

Potential evapotranspiration, ET_p, is the water required by a vigorously growing crop that is adequately supplied with soil moisture and completely shades the ground. ET_p depends almost entirely on the heat energy available and is similar for the common field crops. In southern Alberta, ET_p peaks at about 7 mm/day between mid-July and early August but this value may be exceeded on excessively drying days.

The actual evapotranspiration value, ET, is the amount of water the crop removes from the soil and transpires plus the amount of water evaporated directly from the soil. If soil moisture is below the readily available range, or if the crop is either not fully developed or nearly ripe, actual ET will be less than ET_p. Measured or estimated ET values can be used to indicate the amount of irrigation needed to replenish soil moisture and the point at which irrigation becomes necessary. The technique is explained in the section on budgeting soil moisture and scheduling irrigation.

Total ET for the growing season is greater for perennial crops than for annuals because perennials are already established in the spring and continue vegetative growth later in the fall. Row crops such as sugar beets or corn have lower ET values in the spring than close-seeded crops because they do not establish ground cover as quickly. Short-season crops like green peas or beans have lower seasonal ET values than long-season crops like sugar beets.

When soil moisture is kept readily available, plants take most of their water from the top 50 cm of the root zone. As the water in the upper portion of the root zone is used and soil moisture suction increases, more water is drawn from greater depths. Depths of rooting differ among crops and vary with stage of growth, physical characteristics of the soil, and content and distribution of soil moisture. For practical purposes, rooting depths are as follows: alfalfa 120-180 cm; grass, cereals, flax, rape, and sugar beets 90-120 cm; corn 75-120 cm; potatoes 60-90 cm; and peas 75-90 cm. Unless they are extreme, differences in rooting depth do not cause differences in rate of water use. But rooting depth does determine the amount of water available to the crop. The deeper the root zone, the greater its capacity for storing available water. The root zone of most mature annual crops is about 120 cm deep.

The increase in crop growth associated with improved crop management is usually greater than the increased water use. For example, fertilizers, where required, increase the rate of water use by promoting earlier and faster crop development; but the increased crop growth more than compensates for the increased water consumption.

Crops that are appreciably taller than the surrounding vegetation or crops on small, irrigated fields surrounded by dry land or summer fallow may capture heat from outside the cropped area. This movement of extra heat into the cropped area is known as advection and can cause ET to exceed ET_p slightly. In extremely hot, windy weather, water conduction through the plants may be insufficient to meet the evaporational demand. Then, ET by the crop becomes less than potential evapotranspiration and temporary or incipient wilting may occur.

EVAPOTRANSPIRATION FOR DIFFERENT CROPS

The average daily values of ET, as the season progresses from seeding to harvest, are shown in Fig. 1-14 for the important irrigated field crops in southern Alberta. On any particular day, weather or soil moisture variations

may cause the actual ET to differ appreciably from the mean value. The standard error is listed for each curve; the curves are expected to be accurate within ± this value two-thirds of the time. The curves of alfalfa and grass are constructed as if the crop were not harvested in mid-season. In practice, daily ET is reduced after each mid-season harvest of hay or forage to about 25% of potential values. As regrowth takes place, daily ET increases and reaches normal values within 10 to 15 days.

The data for each curve were obtained over a minimum of 3 and usually 5 or 6 years of study at the Irrigation Research Substation, Vauxhall, Alberta where the soil is a medium-textured loam, typical of much of the irrigated land of southern Alberta. Yields of the crops in these studies were consistently higher than the commercial averages. Soil moisture was maintained in the upper half of the readily available range to allow for full expression of the yield potential. Estimated deep drainage amounted to only about 5% of ET, and low salinity was maintained in the root zone. Average dates for stages of crop development and percentage of ground cover are shown with the curves for the annual crops (Figs. 1-14). ET is best expressed as a function of growth stage rather than time of year because, due to variations in planting date or weather, growth stages do not always occur on the same date each year.

DETERMINING POTENTIAL AND ACTUAL EVAPOTRANSPIRATION

Neither potential nor actual ET can be measured conveniently on farm fields. They can be estimated, however, using instruments which measure evaporation or they can be calculated from meteorological data. Since equipment used to record meteorological data is simpler and more reliable than that used to measure evaporation, calculations based on meteorological data have proven to be the most practical method of estimating ET. The basic relationship between crop water use and the demands of the environment (actual vs. potential ET) has been determined from carefully monitored field plots over a period of many years.

APPLICATION OF EVAPOTRANSPIRATION CURVES

Average daily ET_p, calculated from 16 years of meteorological data, is shown as a broken line in Fig. 15. Actual ET is usually similar to potential ET in midsummer when plants are in full growth. But, during their early and late growth stages, plants cannot utilize all the energy available and actual ET is less than potential ET.

The potential curve provides a common reference for the various crops and a basis on which the crop curves may be transferred from one area to another. It also provides a means of integrating day-to-day weather fluctuations into the scheduling procedure.

The mean values of ET depicted in Figs. 1-14 do not illustrate the wide daily fluctuations that can occur. But, if weather is characterized daily, actual ET can be determined from mean ET in the same proportion that daily ET_p bears to mean ET_p. Relationships of ET with evaporation from evaporimeters such as the class A pan or porous discs may, alternatively, provide the basis on which to estimate daily crop water requirements.

BUDGETING SOIL MOISTURE AND SCHEDULING IRRIGATION

To schedule irrigation according to need, a daily soil moisture budget must be kept. Water is applied when the account shows that the level of soil moisture is low. For most crops, irrigation is needed when half the available soil moisture is used. Exceptions include potatoes, which require that soil moisture be kept in the upper third of the available range, and alfalfa, which can safely use two-thirds of the available soil moisture before irrigation becomes necessary. If irrigation is started when these lower limits of available soil moisture are approached in the budget calculation, the entire field can usually be covered before soil moisture stress becomes serious. A predicted schedule may need to be adjusted for young crops which have very shallow root systems or when irrigation equipment requires many days to traverse a field. Daily deductions of ET from the account should be resumed the day after irrigation is started rather than after the field is completely irrigated.

The authors have shown that, on a medium-textured soil with fairly heavy crops, irrigation according to the above guidelines results in about 5% downward leaching. This leaching is sufficient to prevent the accumulation of salts in the root zone on most soils and with most irrigation waters.

Because the water-holding capability of soil varies with texture, the kind of soil influences the amount of readily available moisture. The root zones of most annual crops at maturity (120 cm) can hold about 120 mm of available water in loamy sand, 150 mm in fine sandy loam, and from 200-250 mm in silt loam, silty clay loam, and clay loam. Soil moisture can safely be depleted by half these amounts.

When soil moisture is reduced, for example, to 50 mm below field capacity on sandy loam or 110 mm on clay loam, irrigation is required to bring the moisture content back to field capacity.

The ET curves were determined from crops for which optimum soil moisture was provided and good agronomic practices were used. When crop growth is below optimum, daily water use values that are lower than those given in the figures may be more realistic. When growth is restricted by inadequate soil moisture, ET values are substantially lower than those shown. When other factors such as low soil fertility limit growth, but soil moisture is adequate, ET values are lowered only slightly. Irrigation requirements during the latter part of the growing season may be reduced for some crops, such as cereals, by allowing greater depletion of stored soil moisture as harvest approaches.

The soil moisture at the start of the budget is preferably determined by oven drying soil samples. Alternatively, the budget could be started about 2 days after a heavy rain or an irrigation if the root zone is replenished to near field capacity. For a medium-textured soil, moisture content is near field capacity when a ball of soil definitely resists crumbling after being firmly squeezed in the hand.

LIMITATIONS AND SPECIAL CONSIDERATIONS

Some very specific soil water relationships limit the effectiveness of simple budget procedures. But these can be successfully accommodated in the more complex budgets calculated with the aid of computers. Several are incorporated in the model described in the following pages.

All soil moisture is not equally available. It is easier for plants to extract water when the soil moisture is near field capacity than when it is approaching the wilting point. This complex relationship has been simulated in the computer program by a logarithmic function.

When the soil surface is bare and wet, evaporation occurs from it in an amount about equal to that which a fully vegetated crop would transpire. The evaporation rate declines as the soil surface dries. It also declines as plants provide increasing ground cover. A simple arithmetic relationship simulates the declining evaporation rate and another factor simulates increasing crop development.

If a water table exists within the crop root zone, it will contribute to plant water requirements. The amount contributed is dependent on both the water table depth and the depth of crop rooting. This program includes a technique to estimate the contribution to ET from water tables of various depths. Although the technique was developed for sugar beets, it is adaptable to other crops.

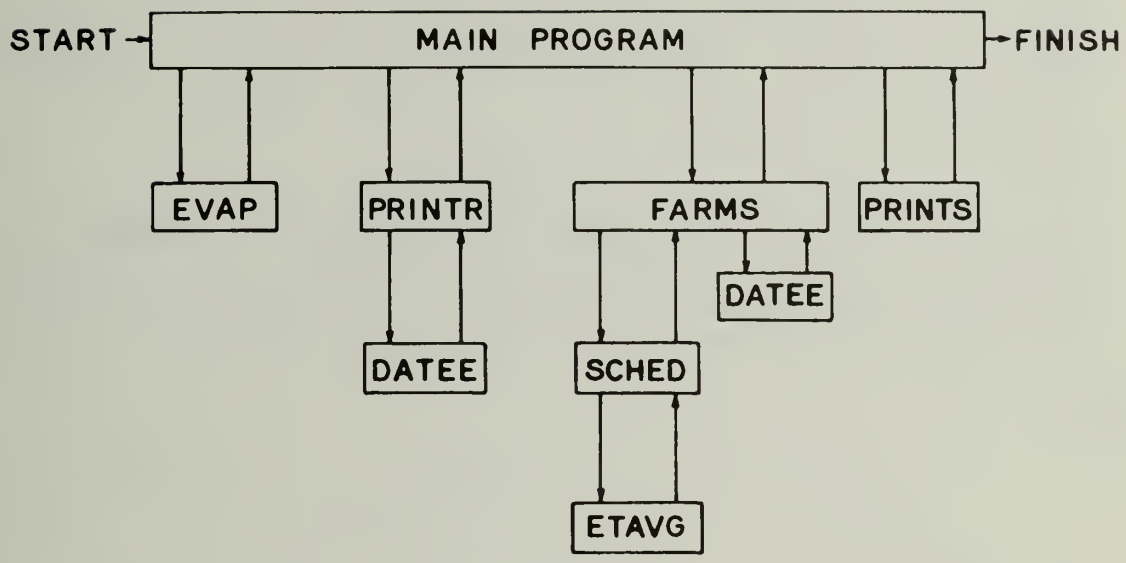
The actual depth of rooting of annual crops increases from germination to a maximum about mid-season. When plants are very small, the soil moisture calculated by a simple budget may be unavailable because it is held below and out of the reach of tiny roots. The need for irrigation at this time is best determined by actually examining the soil in the shallow root zone. The difficulties associated with scheduling for, and irrigation of, very young plants can often be avoided by fall irrigation.

THE LETHIRR COMPUTER SCHEDULING PROGRAM

Numerous computer programs have been developed to assist in irrigation scheduling. The design and sophistication are a matter of individual preference and equipment capability. But crop reference curves and their relation to the crop environment are fundamental to all programs.

LETHIRR, the computerized scheduling program adapted for use in Alberta, was developed by the Agricultural Research Service of the United States Department of Agriculture (Jensen *et al.*). It consists of a main program to which are attached a number of subroutines which calculate ET, assess special conditions, and determine irrigation requirements. Each crop is represented by its own ratio curve which defines the long-term relationship for that particular crop with ET_p.

The scheduling program requires two kinds of input data, fixed and variable. These are introduced successively into the program in the manner indicated in the following flow chart.


START
MAIN PROGRAM
FINISH
EVAP
PRINTR
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DATEE
SCHED
ETAVG

At the beginning of a growing season all fixed information is placed in computer storage. This includes: area transfer coefficients involving mean temperature and elevation; identification of farms and fields; crop curves; planting, harvesting and full cover dates; available soil moisture; initial soil moisture, and irrigation application efficiency. Each time the program is run, usually weekly, the operational variables (air temperature, radiation, precipitation, irrigation, critical irrigation level, and water table depth) are entered.

The output includes calculated ET_p and actual ET for each crop. The crop ET is entered in a moisture budget which calculates soil moisture depletion. This is combined with an estimate of future ET to create a prediction of when the next irrigation will be required and how much water should be applied.

The LETHIRR scheduling program is being adapted and assessed by the extension services of the Irrigation Division of Alberta Agriculture. A copy of the program, including operational instructions, is available from the Agriculture Canada Research Station at Lethbridge, Alberta.

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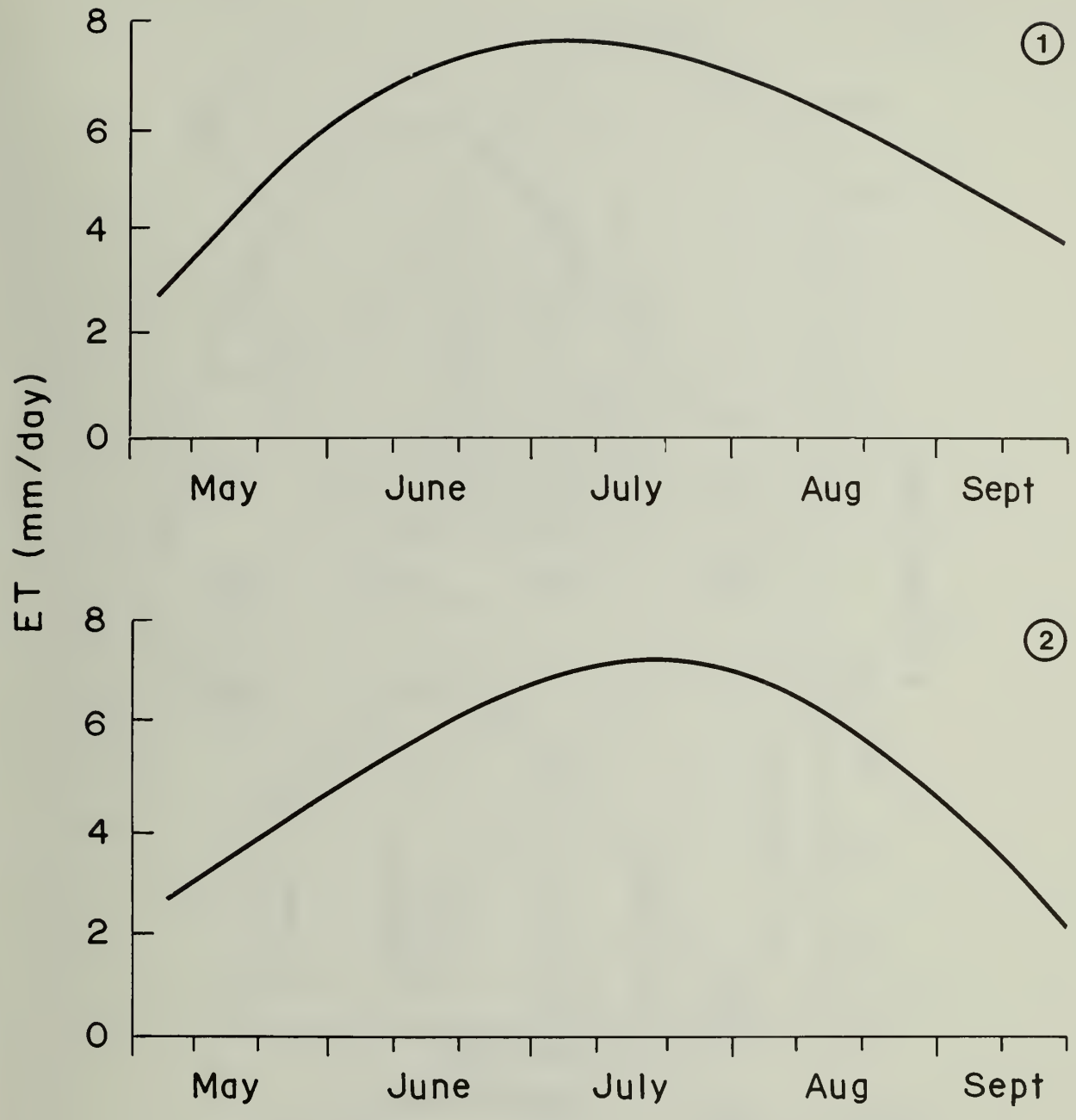
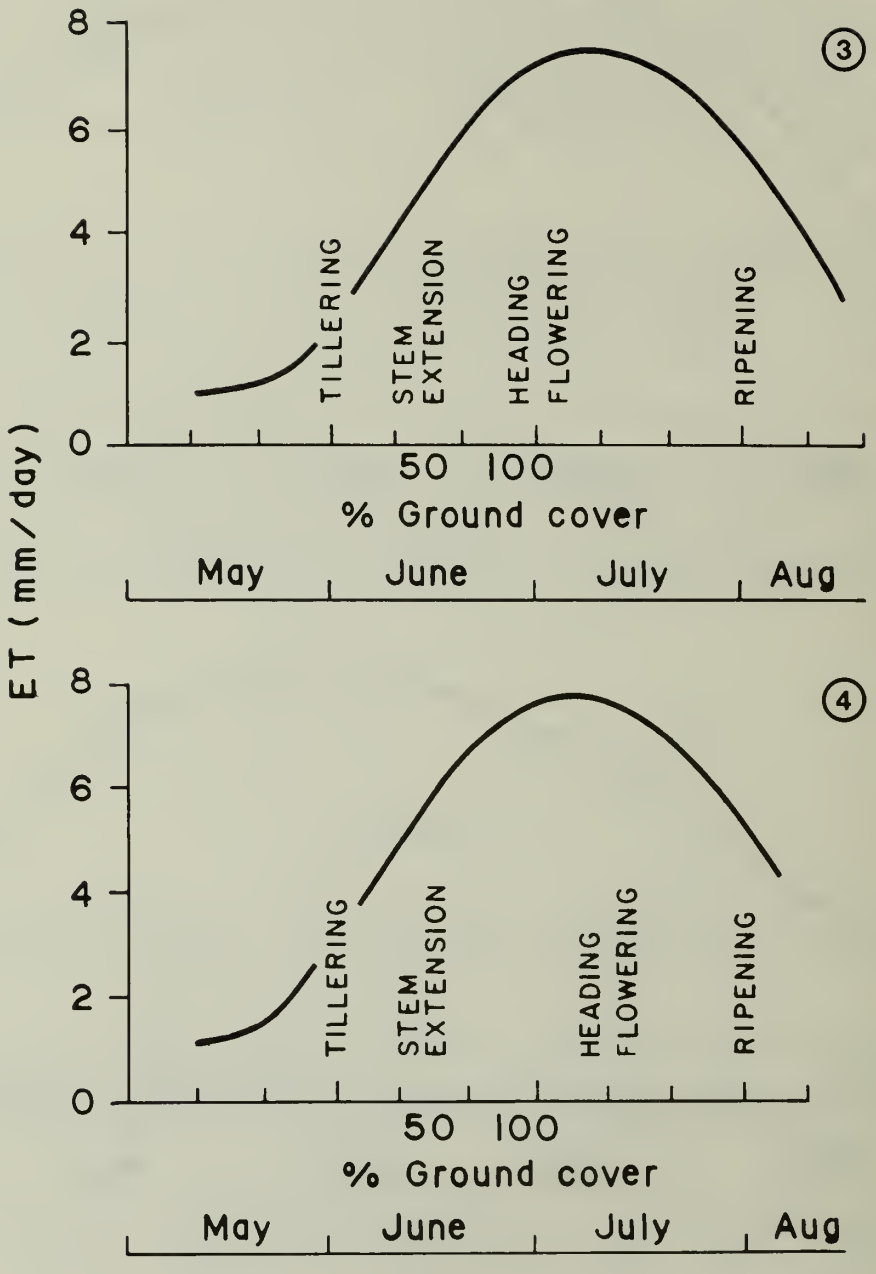
Hobbs, E. H. 1981. Improving farm irrigation management by incorporating water table effects into scheduling programs. Proc. 11th Congress Intern. Comm. Irrig. and Drainage, Grenoble, France. R. 30, Quest. 36: 491-496.

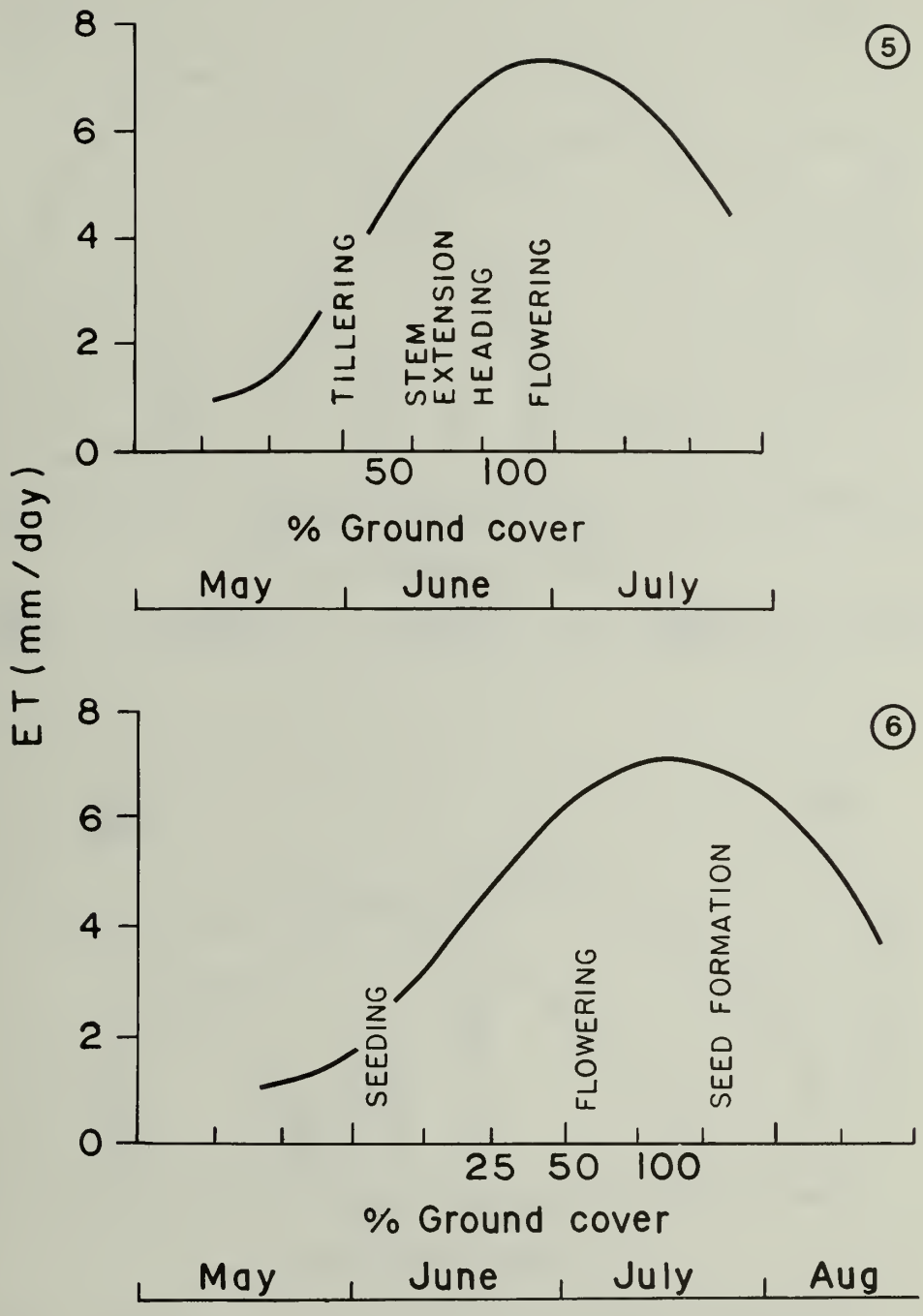
Jensen, M. E., J. L. Wright, and B. J. Pratt. 1971. Estimating soil moisture depletion from climate, crop and soil data. Trans. Am. Soc. Agric. Eng. 14(5): 954-959.



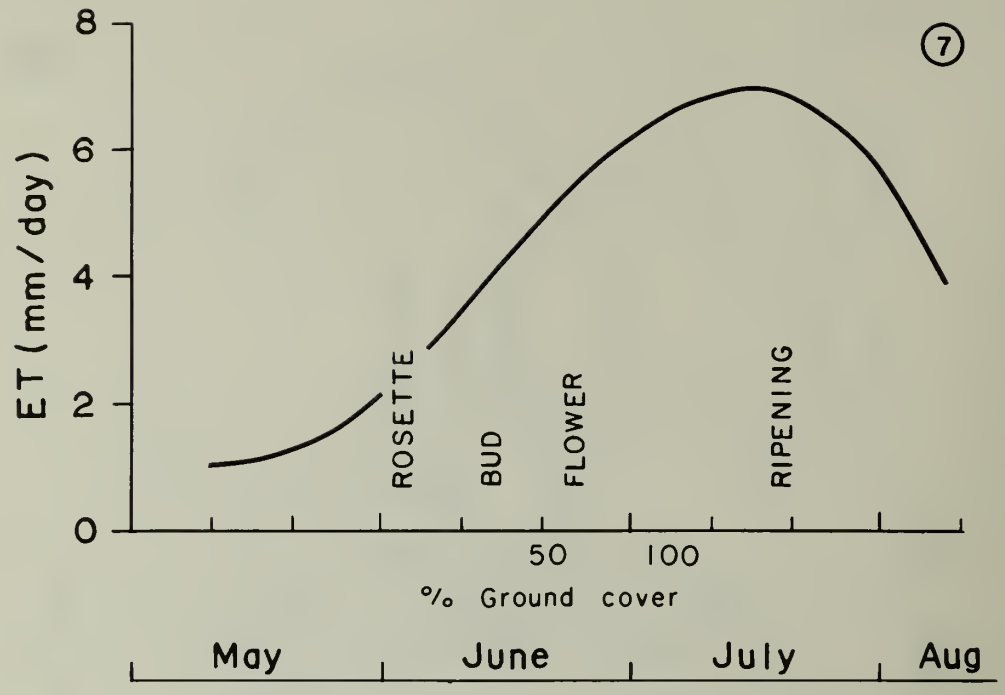
Figs. 1 and 2. Evapotranspiration during the growing season.
1) **alfalfa** - mean of 6 years, SE = 1.01 mm
2) **grass** - mean of 5 years, SE = 0.93 mm

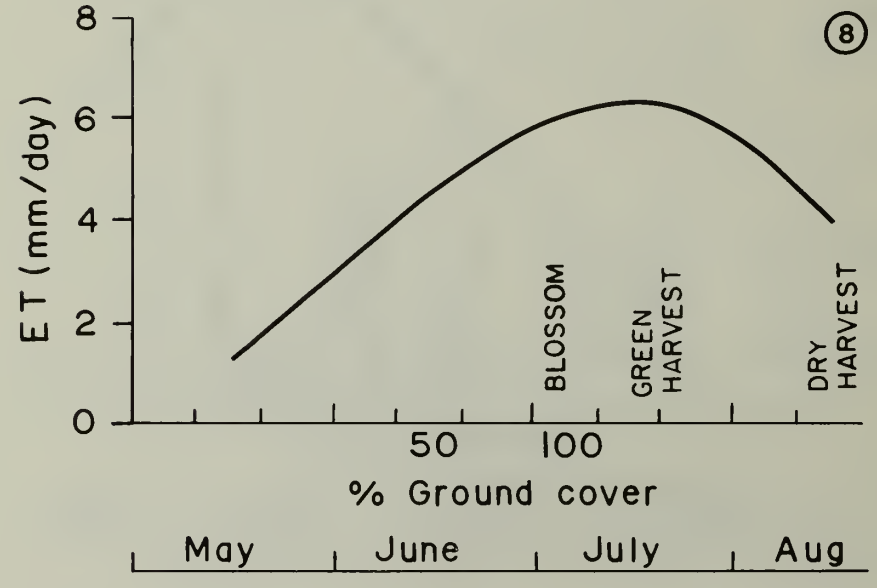


Figs. 3 and 4. Evapotranspiration during the growing season.
3) wheat - mean of 5 years, SE = 0.90 mm
4) oats - mean of 3 years, SE = 1.13 mm

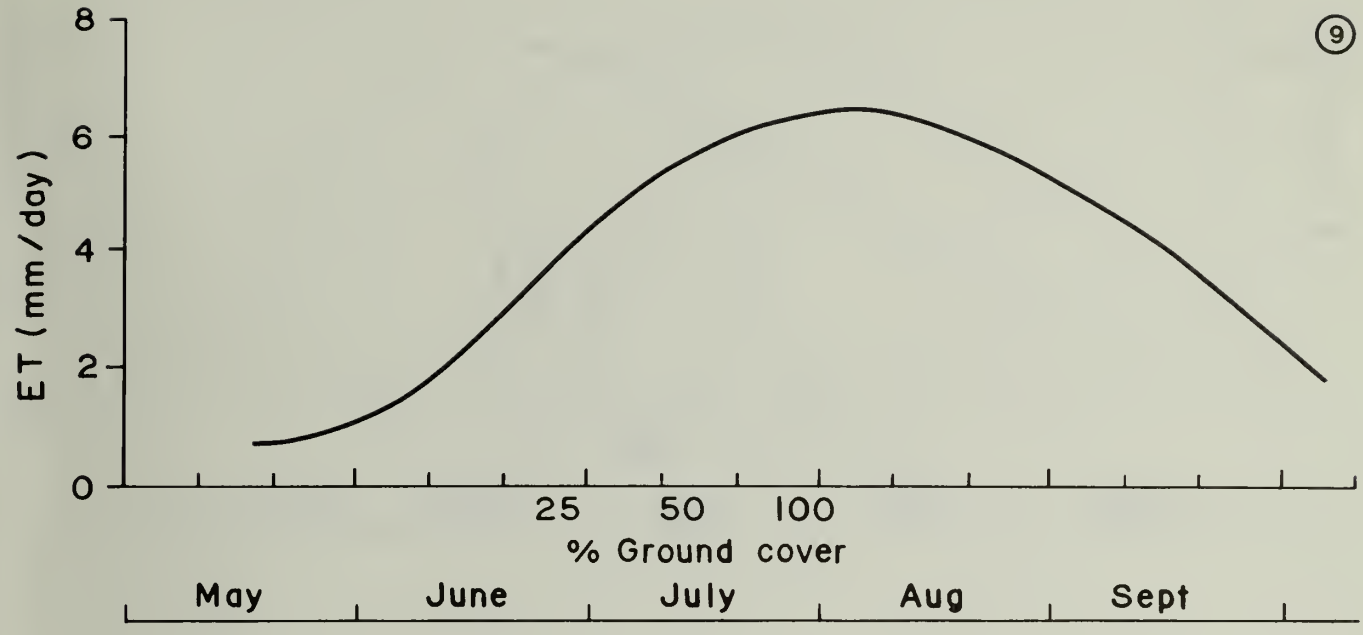


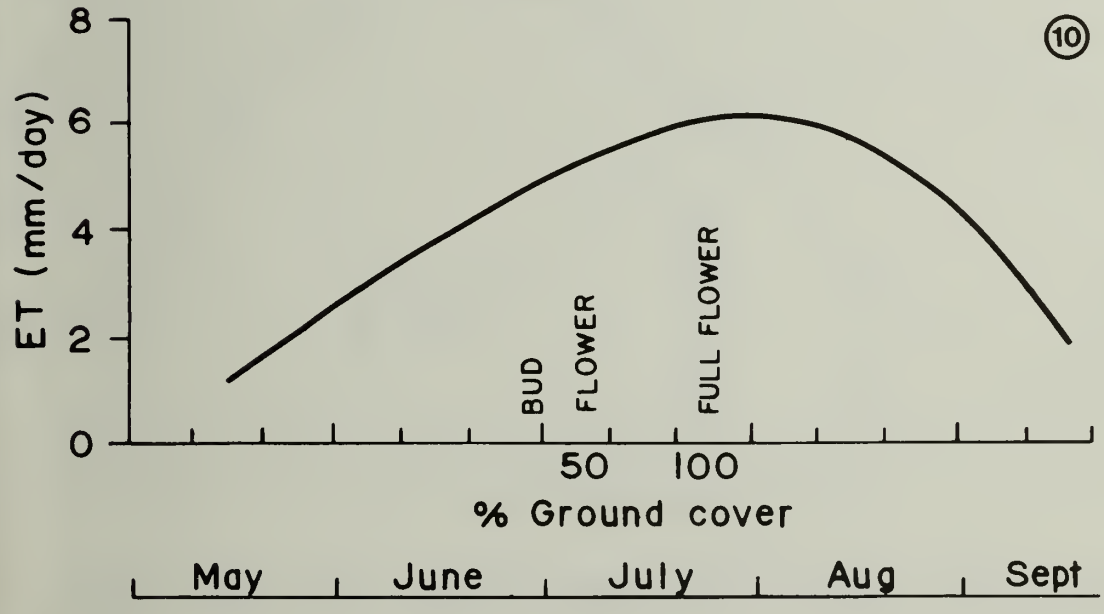
Figs. 5 and 6. Evapotranspiration during the growing season.
5) **barley** - mean of 4 years, SE = 1.01 mm
6) **flax** - mean of 3 years, SE = 1.33 mm



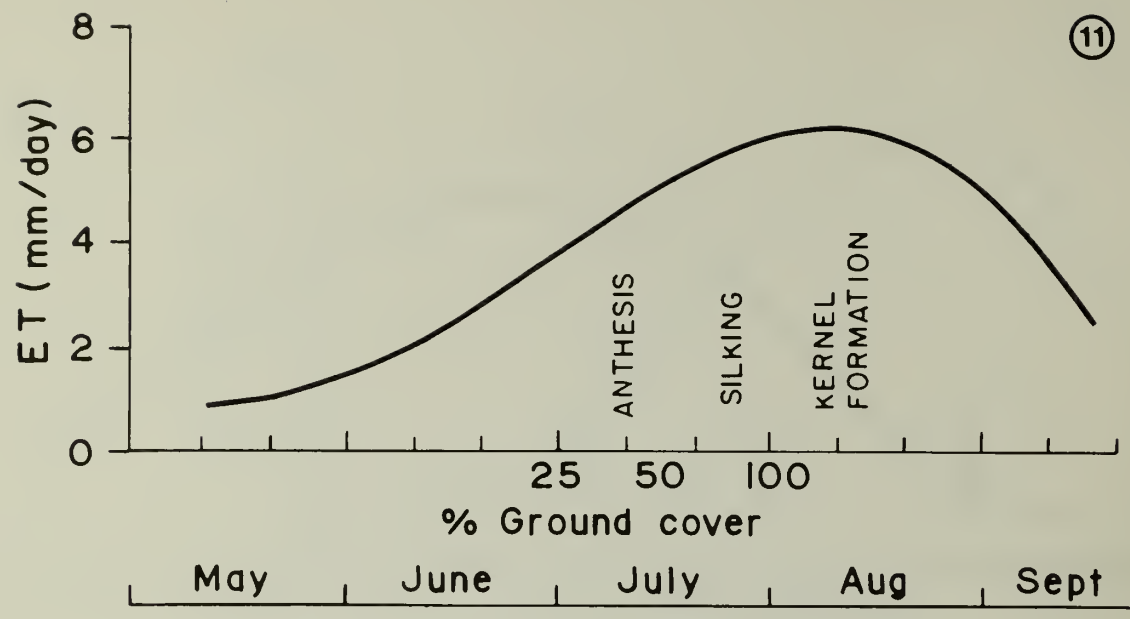


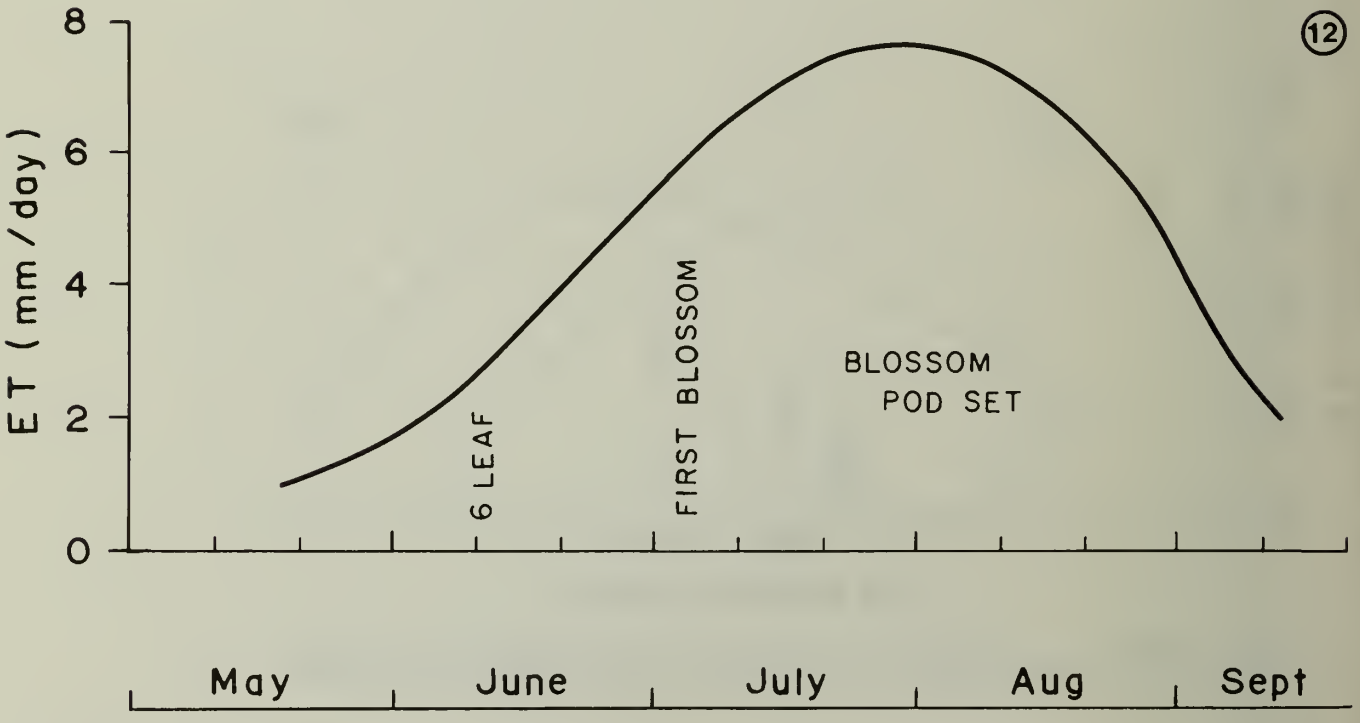
Figs. 7 and 8. Evapotranspiration during the growing season.
7) rape - mean of 4 years, SE = 0.52 mm
8) peas - mean of 4 years, SE = 1.06 mm



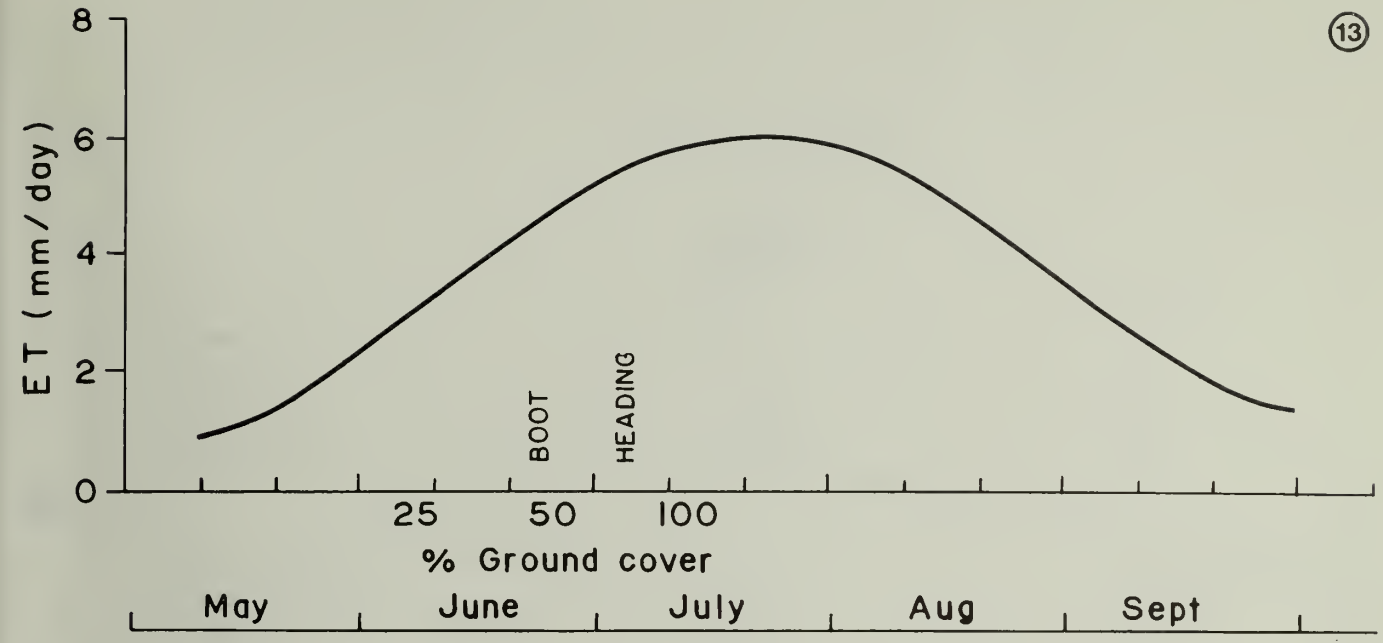


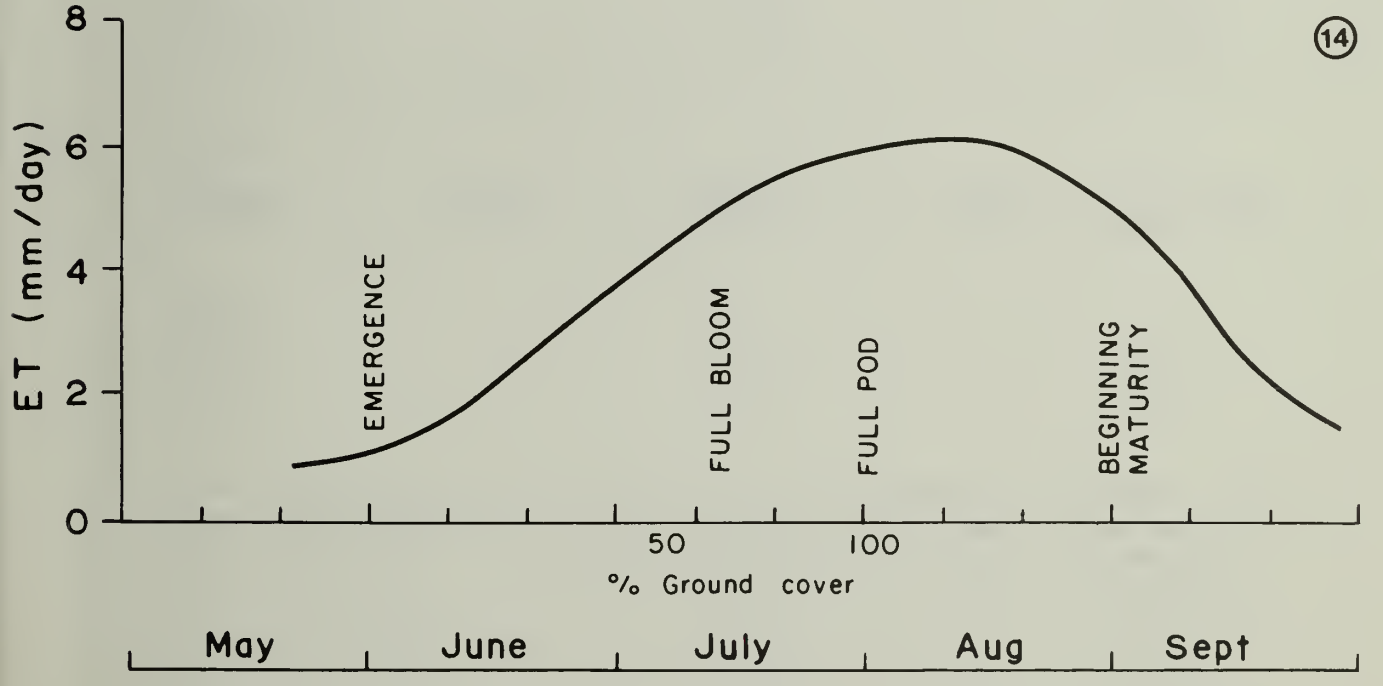
Figs. 9 and 10. Evapotranspiration during the growing season.
9) **sugar beets** - mean of 4 years, SE = 0.80 mm
10) **potatoes** - mean of 4 years, SE = 0.73 mm





Figs. 11 and 12. Evapotranspiration during the growing season.
11) **corn** - mean of 5 years, SE = 1.20 mm
12) **fababeans** - mean of 4 years, SE = 1.64 mm





Figs. 13 and 14. Evapotranspiration during the growing season.
13) **sorghum** - mean of 3 years, SE = 0.84 mm
14) **soybeans** - mean of 3 years, SE = 1.09 mm

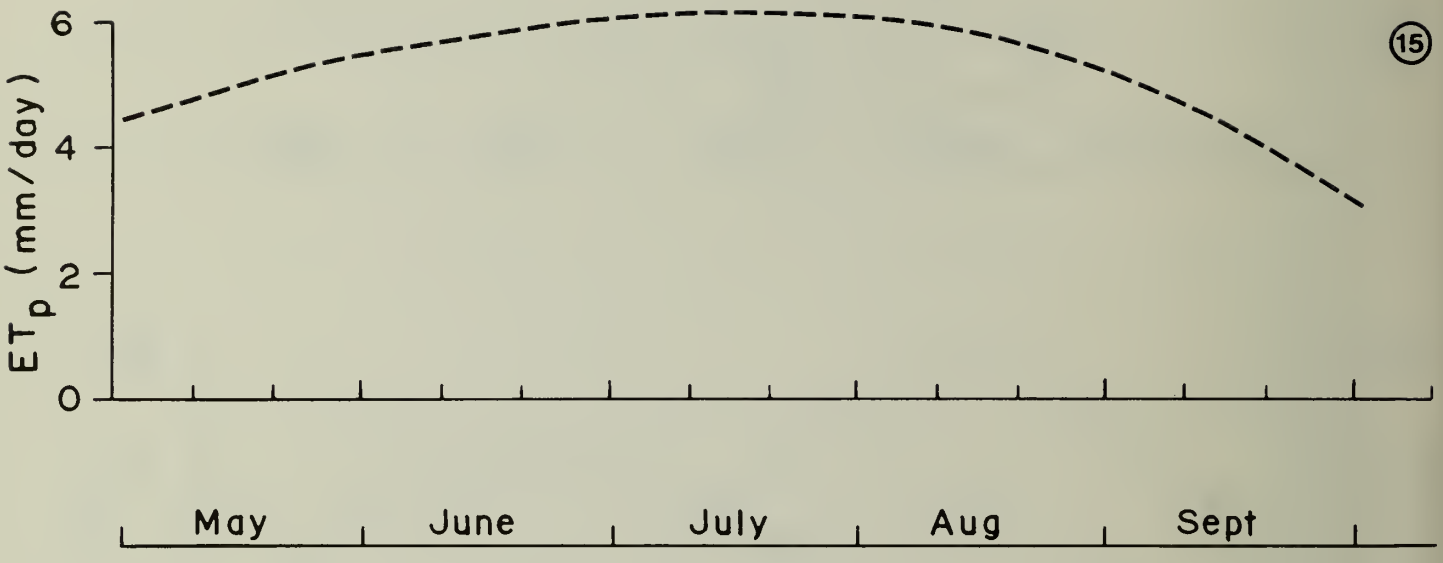


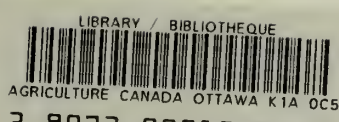
Fig. 15. Potential evapotranspiration based on relationship between evaporation and concurrent crop evapotranspiration. Mean of 16 years, SE = 0.65 mm

CONVERSION FACTORS

Metric units	Approximate conversion factors	Results in:
LINEAR		
millimetre (mm)	× 0.04	inch
centimetre (cm)	× 0.39	inch
metre (m)	× 3.28	feet
kilometre (km)	× 0.62	mile
AREA		
square centimetre (cm^2)	× 0.15	square inch
square metre (m^2)	× 1.2	square yards
square kilometre (km^2)	× 0.39	square mile
hectare (ha)	× 2.5	acres
VOLUME		
cubic centimetre (cm^3)	× 0.06	cubic inch
cubic metre (m^3)	× 35.31	cubic feet
cubic metre (m^3)	× 1.31	cubic yards
CAPACITY		
litre (L)	× 0.035	cubic foot
hectolitre (hL)	× 22	gallons
hectolitre (hL)	× 2.5	bushels
WEIGHT		
gram (g)	× 0.04	oz avdp
kilogram (kg)	× 2.2	lb avdp
tonne (t)	× 1.1	short tons
AGRICULTURAL		
litres per hectare (L/ha)	× 0.089	gallons per acre
litres per hectare (L/ha)	× 0.357	quarts per acre
litres per hectare (L/ha)	× 0.71	pints per acre
millilitres per hectare (mL/ha)	× 0.014	fl. oz per acre
tonnes per hectare (t/ha)	× 0.45	tons per acre
kilograms per hectare (kg/ha)	× 0.89	lb per acre
grams per hectare (g/ha)	× 0.014	oz avdp per acre
plants per hectare (plants/ha)	× 0.405	plants per acre

CONVERSION FACTORS

Metric units	Approximate conversion factors	Results in:
LINEAR		
millimetre (mm)	× 0.04	inch
centimetre (cm)	× 0.39	inch
metre (m)	× 3.28	feet
kilometre (km)	× 0.62	mile
AREA		
square centimetre (cm^2)	× 0.15	square inch
square metre (m^2)	× 1.2	square yards
square kilometre (km^2)	× 0.39	square mile
hectare (ha)	× 2.5	acres
VOLUME		
cubic centimetre (cm^3)	× 0.06	cubic inch
cubic metre (m^3)	× 35.31	cubic feet
cubic metre (m^3)	× 1.31	cubic yards
CAPACITY		
litre (L)	× 0.035	cubic foot
hectolitre (hL)	× 22	gallons
hectolitre (hL)	× 2.5	bushels
WEIGHT		
gram (g)	× 0.04	oz avdp
kilogram (kg)	× 2.2	lb avdp
tonne (t)	× 1.1	short tons
AGRICULTURAL		
litres per hectare (L/ha)	× 0.089	gallons per acre
litres per hectare (L/ha)	× 0.357	quarts per acre
litres per hectare (L/ha)	× 0.71	pints per acre
millilitres per hectare (mL/ha)	× 0.014	fl. oz per acre
tonnes per hectare (t/ha)	× 0.45	tons per acre
kilograms per hectare (kg/ha)	× 0.89	lb per acre
grams per hectare (g/ha)	× 0.014	oz avdp per acre
plants per hectare (plants/ha)	× 0.405	plants per acre



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Hobbs, E. H.
Scheduling irrigation to meet crop demands